Infuence of Land Use / Land Cover on Soil Properties at the Forestry Research Institute of Nigeria (FRIN), Oyo State, Nigeria

*Olajiire-Ajayi, B. L.**

Federal College of Forestry, Jericho, Ibadan

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***CORRESPONDING AUTHOR**

jiirebolanle@gmail.com
+2348030785074

ABSTRACT

Land cover transformation in and around the Forestry Research Institute of Nigeria (FRIN) can significantly alter soil physical and chemical properties, with potential impacts on soil fertility and ecosystem health. This study investigates how different land use types; undisturbed and harvested Gmelina arborea plantations (UGP and HGP) influence soil characteristics at FRIN in Jericho, Ibadan, Oyo State. Soil samples were taken at two depths (0-15 cm and 15-30 cm) and analysed at the IARandT, Moor Plantation soil laboratory for particle size distribution, pH, Organic Carbon (OC), Organic Matter (OM), Total Nitrogen (TN), exchangeable bases, cation exchange capacity (CEC), and micronutrient levels. The results showed differences between UGP and HGP land use types. UGP soils were slightly acidic pH (5.6), while HGP soils were slightly alkaline pH (6.5). At the 0-15 cm depth, UGP had higher OC (10.5), OM (17.68), and TN (1.054) compared to HGP OC (7.64), OM (12.97), TN (0.056). This pattern held at 15-30 cm, with UGP consistently exhibiting richer nutrient profiles. Exchangeable base levels and trace element concentrations in the UGP showed lower levels of Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and trace elements like Fe^{3+}, Zn^{2+}, and Cu^{2+} than HGP, while maintaining higher CEC. The study concludes that differences exist in soil characteristics between UGP and HGP within FRIN. The findings show the importance of sustainable land management practices to support soil fertility and ecosystem health. The study recommends re-afforestation of harvested plantations to preserve soil quality and counteract the negative effects of land use changes.

INTRODUCTION

Land use and land cover (LULC) changes are critical factors influencing soil properties and overall ecosystem functionality (IPCC, 2007b; IPCC, 2013). The transformation of forests, agricultural lands, and urban areas through anthropogenic activities alters soil physical, chemical, and biological characteristics (FAO, 2021). Soil, as a fundamental resource for ecosystem services, is highly sensitive to changes in land use, affecting its physical, chemical, and biological properties (Garedew, 2010). In Nigeria, deforestation, agricultural expansion, and urbanisation have contributed to significant changes in soil fertility and degradation (Akinyemi *et al*., 2022). Understanding the impact of LULC changes on soil properties is essential for sustainable land management and conservation planning.

Land use and land cover changes have been linked to significant declines in soil quality, threatening the sustainability of ecosystems and agricultural productivity (IPCC, 2013). In Forestry Research Institute of Nigeria (FRIN), increasing land use changes driven by clearing of forest, and infrastructural development have raised concerns about their impact on soil characteristics. Previous studies have shown that changes in LULC influence soil organic matter content, nutrient availability, and microbial activities (Olorunfemi *et al*., 2023). However, there is limited research focusing on the extent to which these changes affect soil physicochemical properties within protected research areas like FRIN.

Despite the crucial role of soil in maintaining ecosystem health and productivity, LULC changes continue to alter its properties, leading to issues such as soil degradation, nutrient depletion, and loss of soil biodiversity (Adeyemi *et al*., 2020). The influence of different land use types on soil physicochemical characteristics within FRIN has not been adequately documented. This poses challenges to developing appropriate land management strategies to mitigate soil degradation and enhance soil sustainability. Consequently, the study seeks to assess the effect of land use and land cover changes on soil characteristics within the Forestry Research Institute of Nigeria so as to examine the influence of land cover changes on soil physical and chemical properties.

Understanding the relationship between LULCC and soil characteristics is vital for sustainable land management and environmental conservation. Studies like this are also crucial to global efforts to combat land degradation and achieve Sustainable Development Goals (SDGs) related to life on land, climate action, and sustainable use of ecosystems (United Nations, 2021). The findings of this study will provide valuable insights into the effects of land use changes on soil health within FRIN, serving as a baseline for policymakers, researchers, and land managers (Eze *et al*., 2022). Additionally, the results will guide the development of strategies to mitigate soil degradation and promote sustainable forest management.

METHODOLOGY

Study Area

The Forestry Research Institute of Nigeria (FRIN) sits at coordinates approximately 7.4386° N latitude and 3.8975° E longitude (Figure 1). This area experiences the tropical savanna climate which is characterized by seasonal wet and dry season. The wet phase is from April to October, followed by a dry spell from November to March. Rainfall peaks during the wet months, averaging between 1200mm to 1400mm annually. The temperature stays consistently high year-round, with temperatures soaring between 28°C to 32°C. The area is characterized by a daily relative humidity of approximately 71.9% (Olunloyo *et al*., 2021).

The relief of the area surrounding FRIN is characterized by undulating terrain, consistent with Ibadan's hilly topography. Elevations vary within the range of approximately 150 meters to 275 meters above sea level.

The terrain surrounding FRIN is characterised by undulating landscapes, mirroring Ibadan's hilly topography, with elevations ranging from approximately 150 meters to 275 meters above sea level.

The vegetation around FRIN encompasses a mix of natural forest and managed plantation areas both indigenous and exotic species (Olunloyo *et al*., 2021)

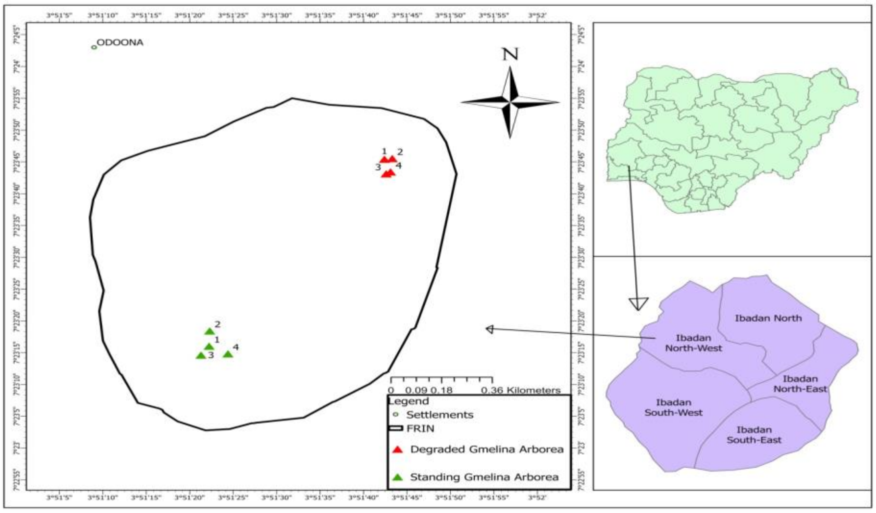

Figure 1: Map of study Area showing location of sample collection

Collection and preparation of soil samples

A hectare of land, measuring 100 m by 100 m, was marked out at each location and divided into 20 × 20 m plot because of the size of the plantations. 10 plots were randomly selected for collection of soil samples. Soil samples was at the 0-15 cm and 15-30 cm depths using soil auger. Consequently, a total of 40 soil samples were collected; 20 samples from each depth. Ten samples were taken at each plantation making a total of 20 sample per plantation. The samples were immediately put into the polythene bags and labelled accordingly. Composite samples were made from the samples. They were thoroughly mixed, air-dried, sieved with 2mm mesh and taken to the Institute for Agricultural Research and Technology (IARandT), Moor Plantation soil laboratory for analysis.

Laboratory analysis

Bouyoucous hydrometer method (Gee and Or, 2002) was used to analysed particle size distribution. The textural class is determined with the result using the United State Department of Agriculture (USDA) textural triangle. A pH meter was used in determining the soil pH. The soil samples were mixed with distilled, and the pH of the resulting solution was measured.

Organic carbon was determined using the Walkey-Black method. Total Nitrogen determined using total nitrogen by Kjeldahl method (Bremner and Mulvaney, 1982). The samples were digested in sulphuric acid, using $CuSO_4$ as catalysts, converting N to NH_3, which is distilled and titrated (Bremner and Mulvaney, 1982).

The exchangeable bases (Ca^{2+}, Mg^{2+}, K^+, Na^+) were extracted with 1N neutral ammonium acetate. Exchangeable Ca^{2+} and Mg^{2+} was determined by atomic absorption spectrometer while K^+ and Na^+ was determined by flame photometer. Extractable micronutrient of Mn^{2+}, Zn, $^{2+}$,Cu^{2+} and Fe^{3+} was leached with 0.1N HCL using wear and summer (1948) method, and was determined in atomic absorption spectrophotometer. Base Saturation (BS) was computed by summation of exchangeable bases divided by the ECEC.

Statistical Analysis

The soil properties were analysed using descriptive statistics and Least Significant Different (LSD) was used to separate means where significance occur at $\alpha_{0.05.}$

RESULTS AND DISCUSSION

Land Use and Soil Particle Size Distribution

Particle size distribution significantly influences soil properties such as permeability, water retention, and compaction. It impacts soil structure and fertility, drainage capacity, and the ability of roots to penetrate the soil (Brady and Weil, 2016). It comprises proportions of sand, silt, and clay.

Table 1 shows analysis of particle size distribution among the land uses and soil depth at the study sites.

Table 1: Land Use and Particle Size Distribution

Land use type	Depth	Sand	Silt	Clay	Textural Class
UGP	0-15	21.38	72.77	5.79	Silt loam
	15-30	19	71.8	4.71	Silt loam
HGP	0-15	25.39	69.9	9.2	Silt loam
	15-30	24.8	67.8	8.52	Silt loam
LSD		1.073	1.013	0.765	
% CV		5.2	1.6	12	

Note: LSD = Least Significant Difference at 0.05 significant level; % CV = Coefficient of variation

In the UGP, the Sand content decreases with depth (21.38% to 19%) while under the CGP, the Sand content is higher than UGP and also decreases slightly with depth (25.39% to 24.8%). In the UGP, the Silt content is relatively high and decreases slightly with depth (72.77% to 71.8%) while in the CGP, the Silt content is lower compared to UGP and decreases with depth (69.9% to 67.8%). In the UGP, Clay content decreases with depth (5.79% to 4.71%) while in the CGP, Clay content is higher compared to UGP and decreases with depth (9.2% to 8.52%).

The LSD values for sand (1.073), silt (1.013), and clay (0.765) indicate that the differences in soil texture between UGP and HGP are statistically significant. The % CV shows that the variability in silt content is the lowest (1.6%), indicating consistent measurements, while clay content has the highest variability (12%).

The observed differences in soil texture can be attributed to the impact of land use on soil properties. HGP generally have higher sand and clay content but lower silt content compared to UGP. The removal of vegetation from a soil can disrupt soil structure, leading to increased sand and clay proportions (Mulat *et al*., 2021)

Generally, textural class is influenced to a large degree by parent materials as it is not impacted over a short time (Kiflu and Beyene, 2013). The soils under the land uses were in the Silt loam textural class. The highest percentage of Sand, Silt and Clay were highest at the 0-15 cm depth under the two land uses. Percentage of soil composition decreases with depth under the two land use managements.

The clay particles however increased with increasing depth under the two managements. The finding of Oyebiyi *et al*., (2018) for soils in the Ife and Ondo regions of southwest Nigeria aligns with this outcome. However, the low clay content may be a result of surface erosion brought on by run-off, clay migration, or a combination of these (Isienyi *et al*., 2021).

Land Use and Soil Chemical Properties

Soil pH measures the acidity or alkalinity of soil on a scale of 0 to 14, with 7 being neutral. pH is a function of H^+ ion concentration (Malik. and Haq, 2022). The soil pH is the most critical factor influencing plant growth performance (Ajon and Anjembe, 2018). It impacts soil microbes and their activity, the formation and availability of nutrients for plant uptake, ion exchange, and the overall stability of the soil (Ajon and Anjembe, 2018; Akintola *et al*., 2020).

Table 2 shows the analysis of the soil pH and some soil chemical properties under the different land use types.

Table 2: Land Use and Soil Chemical Properties

Land use type	Depth	Ph	OC (%)	OM (%)	TN (~~%~~)
UGP	0-15	5.7	10.05	17.68	1.054
	15-30	5.4	8.51	14.45	0.072
HGP	0-15	6.5	7.64	12.91	0.056
	15-30	6.5	4.67	8.11	0.058
LSD		0.112	0.28	0.58	0.039
% CV		2	3.9	4.8	13.5

Note: LSD = Least Significant Difference at 0.05 significant level; % CV = Coefficient of variation

Table 2 shows that in the UGP, the soil pH decreases slightly with depth (5.7 to 5.4). Under the HGP, the soil pH remains constant at 6.5 at both depths. The soil pH under the UGP land use type was slightly acidic to neutral with a value of 6.5 under the UGP at the two depths. This is likely a result of the soil's acidic nature caused by extensive weathering. The soil pH was acidic with value of 5.7 under the HGP. According to reports, forest soils are naturally acidic (Malik and Haq, 2022). Most forest soils are acidic with pH range of 2.0-7.0 and some with values less than 7.0 (Akintola *et al*., 2020). This observation is at odds with the findings of Fasina *et al*., (2007) and Sharu *et al*., (2013).

The LSD (0.112) indicates the differences are statistically significant.

Land Use and Soil OC, OM, TN

In the UGP, the organic carbon (OC) content is higher at both depths, decreasing from 10.05% at 0-15 cm to 8.51% at 15-30 cm. In contrast, the HGP has lower OC levels, which drop significantly from 7.64% at 0-15 cm to 4.67% at 15-30 cm. Also, the In the UGP, Organic Matter (OM) is higher, decreasing from 17.68% at 0-15 cm to 14.45% at 15-30 cm. In the HGP, OM is lower, also decreasing with depth from 12.91% at 0-15 cm to 8.11% at 15-30 cm.

An increase in litter amount is believed to produce higher OC and OM. In addition, the rate of plant litter decomposition and dead soil fauna and microbes in the UGP floor enhance OC (Akinde *et al*., 2020). The result confirms the conclusions of Jamala and Oke (2013) who reported higher OC value under natural forest compared to fallow land. The finding also agrees with studies of Houghton (2003); Alcantara *et al*., (2016) who stated that OC is markedly affected by land use type.

The LSD value of 0.28 indicates significant differences, highlighting the impact of land use on OC. The LSD value of 0.58 also shows significant differences in OM, with HGP having lower OM probably due to less litter as a result of vegetation clearance.

The highest TN (1.0543%) was observed in the UGP. This might be associated to better OM accumulation from the plant biomass return to the soil. The lowest TN value (0.03%) was observed under the HGP (Table 2)

This might be due to soil erosion, volatisation of Nitrogen due to vagaries of weather. This finding is consistent with the findings of Admasu *et al*. (2014) and Chemeda *et al*. (2017), both of whom documented the highest total nitrogen (TN) values in standing forests. Similarly, Admas (2018) and

Fekad *et al*. (2020) also observed elevated TN values in forested areas. The highest total nitrogen (TN) value recorded within the UGP exceeded the FFD (2012) standard, which considers a range of 0.21-0.24% as moderately high. This contrasts with the findings of Akintola *et al*. (2020), who reported lower TN values ranging from 0.35-0.66 g/kg in the Gambari forest reserve. The elevated TN levels in the soil may stem from various factors, including a reduced rate of soil organic matter decomposition, limited leaching, and erosion, as indicated by previous studies (Isienyi *et al*., 2021). Moreover, this could be linked to a higher carbon content, which serves as the primary source of TN (Toru and Kibret, 2019).

Total nitrogen (TN) values typically decline with greater soil depth, with the highest TN concentration commonly found at depths of 0-15 cm under both the UGP and HGP. In the UGP, total nitrogen (TN) is higher at the top soil and decreases sharply with depth, from 1.054% to 0.072%. In the HGP, TN is much lower and remains consistent with depth, ranging from 0.056% to 0.058%. This phenomenon is likely attributed to the higher organic matter (OM) content in the surface or topsoil across all land use management practices. Additionally, the accumulation of substantial plant biomass, animal waste, and other debris in the topsoil could contribute to the elevated TN levels. Similar findings were reported by Chemeda *et al* (2017).

The LSD values indicate significant differences between UGP and HGP for pH, OC, OM, and TN. The % CV shows variability within acceptable limits, with TN having the highest variability at 13.5%.

Land Use on Exchangeable Bases

Table 3 shows illustrate the effect of land use on soil exchangeable bass under the different land use types.

Table 3: Land Use Type and Soil Exchangeable Bases

Land use type	Depth	Ca^{2+}	Mg^{2+}	K^{+}	Na^{+}	CEC	BS
UGP	0-15	0.2	0.17	0.417	0.298	1.19	96.6
	15-30	0.16	0.11	0.382	0.237	1.03	95.5
HGP	0-15	0.26	0.45	0.517	0.37	2.37	86.3
	15-30	0.21	0.83	0.42	0.261	1.81	85.3
LSD		0.039	1.48	0.0125	0.0213	0.049	20.81
% CV		13.5	56.5	3.2	8.1	3.4	29.2

Note: LSD = Least Significant Difference at 0.05 significant level % CV = Coefficient of variation

The highest value of exchangeable bases was recorded in the UGP with values of 0.25, 10.48, 0.517 and 0.37 (cmol/kg) for Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} respectively. Mg^{2+} has the highest value of 10.54 cmol/kg under the UGP. This value could be related to soil properties such as pH, organic matter content, and texture which can influence manganese availability and retention in soil. High OM content can lead to elevated Mg^{2}+ accumulation (Table 4.3).

All exchangeable bases decreased with increasing depth. This observation contradicts the finding by Tilahun (2015) and Adam (2018) who noted increased in exchangeable bases with increasing depth.

Base saturation (BS) is the total amount of basic cations (Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}) in a soil. Increased BS is generally correlated with improved soil fertility (Perry and Amacher, 2007). BS of >50 % indicates a fertile soil while BS <50 % implies the opposite (Ajon and Anjembe, 2018). The average percentage of BS ranged from 96.58 - 86.13 % under the two land use management at both 0-15 and 15- 30 cm. These values are far about the 50% benchmark for fertile soils and thus, the soil samples can be considered fertile. This result is consistent with that of Tufa *et al*. (2019) asserted that land use type impact selected soil characteristics.

CEC serves as an indicator of soil fertility, and the values are primarily influenced by the pH level (Yekini *et al.*, 2022). Soil with high CEC can store large amounts of cationic nutrients (Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}) or acid generating cations of Al^{3+} and H^{+}. A CEC value of < 12 is considered as having a minimum value of soil fertility (Ajon and Anjembe, 2018) although Nigerian soils have reported to have a low CEC value (FAO, 2006). The CEC was low at both depths under the land uses.

The LSD values indicate significant differences between UGP and CGP for (Na^{+}, K^{+}, Mg^{2+}, Ca^{2+}, and CEC.

Land Use type and Soil Extractable Micronutrients

The table 4.4 presents the concentrations of extractable micronutrients (Fe^{3+}, Mn^{2+}, Zn^{2+}, and Cu^{2+}) in soil samples taken from different depths (0-15 cm and 15-30 cm) under two land use types UGP and HGP.

Table 4: Land Use and Soil Extractable Micronutrients

Land use type	Depth	Fe^{3+}	Mn^{2+}	Zn^{2+}	Cu^{2+}	Pb^{2+}
UGP	0-15	0.27	0.0271	0.215	0.027	0.0029
	15-30	0.099	0.01	0.134	0.0099	0.0026
HGP	0-15	1.23	0.033	1.28	0.052	0.038
	15-30	0.866	0.026	0.914	0.0329	0.02
LSD		0.1032	0.0113	0.014	0.0071	0.0039
%CV		18.5	51.9	2.4	25.6	27

Note: LSD = Least Significant Difference at 0.05 significant level, % CV = Coefficient of variation

Table 4 shows that lower concentrations of extractable micronutrients were observed in the UGP compared to HGP, particularly at deeper soil levels (15-30 cm). Fe^{3+} value under the UGP was 1.23 mg/kg at 0-15 cm, and 0.87 mg/kg at 15-30 cm, while in the HGP was 0.2 mg/kg at 0-15 cm, and 0.09 mg/kg at 15-30 cm. Fe^{3+} concentrations were high at both depths in the UGP compared to CGP. This indicates that the UGP supports greater availability of iron, likely due to more organic matter decomposition and less soil disturbance.

Mn^{2+} concentration under the UGP was 0.033 mg/kg at 0-15 cm, and 0.026 mg/kg at 15-30 cm. It was 0.02 mg/kg at 0-15 cm and 0.01 mg/kg at 15-30 cm in the HGP. Zn^{2+} concentration level in the UGP was 1.28 mg/kg at 0-15 cm, and 0.91 mg/kg at 15-30 cm while in the HGP it was 0.22 mg/kg at 0-15 cm, and 0.13 mg/kg at 15-30 cm. Cu^{2+} concentration level in the UGP was 0.05 mg/kg at 0-15 cm, and 0.03 mg/kg at 15-30 cm while in HGP; the value was 0.03 mg/kg at 0-15 cm, and 0.01 mg/kg at 15-30 cm respectively.

There was high concentration of Mn^{2+} in UGP at both depths. This implies that the intact vegetation and litter in UGP contribute to higher manganese levels. UGP Significantly had higher Zn^{2+} and Cu^{2+}concentrations, reflecting better nutrient cycling and retention due to organic matter from vegetation. The UGP has higher levels of essential micronutrients, indicating better nutrient cycling and soil fertility due to the presence of organic matter and reduced soil disturbance. In both land use types, micronutrient concentrations decrease with soil depth. This is typical as the topsoil generally contains more organic matter and nutrients due to litter decomposition and root activity. The greater decline in micronutrient levels with depth in HGP suggests that clearing exacerbates the loss of nutrients from the surface layer, potentially impacting plant growth and soil health over time.

The LSD values suggest that differences in heavy metal concentrations between UGP and HGP are significant for most metals. The small LSD values for Fe^{3+} (0.1032), Mn^{2+} (0.0113), Zn^{2+} (0.014), Cu^{2+} (0.0071), and Pb^{2+} (0.0039) indicate that even slight differences in concentrations are statistically significant.

Studies have shown that land use types can significantly increase the concentration of micronutrients in soils (Sharma *et al.* 2015) found different level of micronutrient concentration in soils subjected to different land uses. The observed decrease in extractable micronutrients with depth is consistent with findings by Alloway (2013), who reported that surface soils tend to accumulate more micronutrients due to deposition from atmospheric sources.

CONCLUSION

The study confirms that vegetation clearance and land use changes adversely affect soil quality by reducing organic matter, nutrient levels, and overall fertility. These changes have broad ecological implications, potentially impacting plant growth, biodiversity, and environmental sustainability. The study recommends re-afforestation of harvested plantations to preserve soil quality and counteract the negative effects of land use changes.

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